BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: LPM Landing and 14 Day CSM Orbital Missions - Case 340

DATE: August 12, 1968

FROM: I. Silberstein

## ABSTRACT


Lunar Payload Module (LPM) landing, aided by a CSM, may be better justified if it could be carried out in conjunction with a 14-day orbital mission. The compatibility of such a mission with the ΔV budget and with a continuous abort requirement is investigated. It is found that a capability of landing the LPM at any given point on the moon and retaining a continuous abort capability exists, but is achieved at the cost of reduced areal coverage. A 14-day polar orbit mission while landing the LPM at any point on the lunar surface is possible if the time limit on the LPM descent activation is removed.

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# MEMORANDUM FOR FILE

## INTRODUCTION

Dual launches under consideration for the mid-seventies require a surface rendezvous of a manned Lunar Module (LM) and an unmanned Lunar Payload Module (LPM). These missions require that the LPM be delivered to the rendezvous point on the lunar surface prior to the launch of the LM. Some of the LPM landing methods currently under consideration call for CSM assistance in navigating the LPM to its landing point. But this task alone may not justify a manned Saturn V launch. If, however, a 14 day orbital mission were possible in conjunction with the LPM landing, such a mission may be justified. It will allow coverage of large areas on the moon by the CSM and the performance of many remote sensing and photographic experiments.

Two questions must first be answered. Is the CSM capable of aborting at any time during the 14 days in orbit around the moon? Can the CSM deliver the LPM to any point on the lunar surface?

## GRAPHICAL METHOD

TRW[1] performed an extensive study of the ΔV requirements for Lunar Orbit Insertions (LOI) and Trans-Earth Injections (TEI), for different lunar orbit inclinations and longitudes of the ascending node of the initial and final orbits. Two burn injection maneuvers were used throughout. Their study was based on the following major assumptions:

1. Earth phase of TL and TE trajectories lies nearly in the moon's orbit plane.

2. The moon is at maximum distance from the earth and its orbit is assumed circular.

3. Time from Trans-Lunar Injection to LOI is between 60 and 132 hours.

4. Only retrograde orbits are considered.

5. Lunar parking orbit is circular at 80 nautical miles altitude.

6. Patched conic approximation is used.

7. Inclination of moon's equator to moon's orbit plane is zero.

8. Librations are neglected.

9. The lunar orbit insertion $\Delta V$ for a given initial orbit is the same as the transearth $\Delta V$ of a final orbit whose inclination is the same and whose node is its negative.

10. The moon's potential is assumed to be equivalent to a spherical moon.

In addition, we assume that midcourse corrections in both translunar and transearth flights are 100 fps each and that the LPM engine must ignite as soon as orbit determination and LPM platform alignment have been completed, following LOI. This last assumption is dictated by the supercritical helium system used to pressurize the LPM descent propellants. The existing system requires that no more than approximately 140 hours elapse between launch and descent propulsion ignition.

Two CSM-LPM configurations are considered which include the latest available weight and performance estimates.[2]

Configuration 1*

The CSM is unchanged except for an additional 2,300 lbs necessary to support two astronauts[3] for a long duration (up to 25 days total mission duration). The LPM is assumed to weigh 32,000 lbs, of which 17,500 are fuel. The CSM inert weight is 27,100 lbs at LOI and the SM contains 39,740 lbs of fuel. The service propulsion system $I_{sp}$ is 313 seconds. Total weight is 98,840 lbs.

Configuration 2

Block I tanks are used in the SM, allowing 44,000 lbs of fuel. The rest of the CSM is the same as in Configuration 1. The LPM has been lightened by 4,000 lbs, 2,000 lbs each of payload and fuel, and weighs 28,000 lbs. The total weight is 99,100 lbs.

*Neither configuration includes weight estimates for orbital experiments. The additional weight, however, will slightly change the quantitative statements but not the main conclusions of this work.

The total $\Delta V$ capability of each configuration is not a fixed number but is dependent on the amount of fuel used before LPM-CSM separation.

Figures 1-7[1] depict the $\Delta V$ required for LOI after a given TL flight time, as a function of the initial lunar orbit inclination and ascending node longitude. If, for each flight time we choose a fixed inclination, we can find the $\Delta V$ required for LOI at any ascending node longitude. These curves are plotted in Figures 8-12.

We assume now that the CSM must be able to abort at any time with a TE flight time of 132 hours. This assumption means that the failure forcing the abort is not time critical (e.g., life support system) but rather an impending failure of the propulsion system. During a 14 day orbital stay, each orbital inclination is associated with a maximum 132 hour TE abort $\Delta V$ (Point A, Figures 8-12). To this abort $\Delta V$ we must add 100 fps for midcourse correction. We can now find the $\Delta V$ available for LOI remembering that 100 fps should be left for a midcourse correction on the translunar phase. That $\Delta V$ limit, which is different for each of the two configurations considered (Table I), may be drawn onto Figures 8-12. The LOI $\Delta V$ required for a given orbital inclination is a function of the initial ascending node longitude and TL flight time. If, for some node longitude the $\Delta V$ required for LOI is less than the $\Delta V$ available ($\Delta V$ limit), then that combination of inclination and node longitude is permissible. The $\Delta V$ limit line defines a whole range of such permissible node longitudes for each orbital inclination (Figures 8-12).

We can now draw on a Mercator projection of the moon the envelopes of the ground traces of these permissible orbits (Figures 13 and 14). The permissible nodes are different for each orbital inclination. Inspecting Figures 13 A-E and 14 A-E, we can imagine the accessible area to be an envelope which, as the orbital inclination decreases continuously, sweeps the whole surface of the moon. Thus it is obvious that any point on the moon is accessible with at least one combination of initial node longitude and inclination. The question is, rather, which is the highest inclination orbit that passes over the point of interest on the lunar surface and maximizes orbital coverage.

Figures 15 and 16 show those areas which are <u>not accessible</u> with orbits whose inclination exceeds a given number. For example, point A on Figure 15 is inaccessible with an orbit whose inclination is 30° but may be reached with a 20° orbit. Point B is not accessible with a 30° orbit since its latitude is higher than 30°, but is accessible with a 45° orbit. Finally, point C is accessible with a 30° orbit having a latitude lower than 30° and being outside the area of inaccessibility for such orbits.

By tracking back the data, it is possible to find for a given point on the moon not only the inclination but also the ascending node of the permissible orbit and thus also the trans-lunar flight time, the actual LOI $\Delta V$, and whether a shorter abort TE flight time is possible (see Appendix).

The maximum $\Delta V$ for LOI (during a 132 hour TL flight) decreases with decreasing inclination. For each of the two configurations, there exists an orbit inclination for which the LOI $\Delta V$ is equal to the maximum TEI $\Delta V$ for a 132 hour TE flight. Since maximum TEI and LOI $\Delta V$ are assumed to be equal in this study, it follows that LOI is possible with 132 TE flight time at the worst case ascending node. Thus, for that inclination, all other ascending node longitudes are also permissible. The values of these "critical inclinations" for each configuration are the starred values in Table I. Any point on the lunar surface whose latitude is equal to or lower than the "critical inclination" may be overflown by a CSM whose orbit has a "critical inclination".

R. Sehgal (private communication) expressed the opinion that the supercritical helium system could be replaced with a gaseous nitrogen system under high pressure. This change would incur weight penalties but will allow two weeks or more from launch to descent propulsion ignition. Even with substantial weight penalties the CSM-LPM combination could be inserted into a polar orbit at some particular node longitude. (Within certain bounds the increased payload could be traded for a narrower choice of ascending node longitudes available with a polar orbit.) The CSM and LPM would remain coupled until the combination passes over the landing site, when separation and LPM landing would occur. Thus, a complete coverage of one half of the lunar surface could be possible with each LPM mission. The precise location of this half will be determined by the critical ascending node longitude.

Such missions will have the additional advantage of emergency use of the Descent Propulsion System for time critical aborts. Thus, it may be advantageous to find a polar orbit initial node near and to the west of the landing site. The LPM would be landed near the end of the mission and time critical aborts would be available during most of the mission. The Marius Hills site is a case in point. A polar orbit may be achieved even with configuration 1, at a node longitude 3° west of the site. During the whole 14 day mission until separation, a 72 hour TE abort is available.

Even the loss of area coverage resulting from decreasing the CSM orbit inclination may not be detrimental to an orbital science mission. (The coverage will be more extensive and more varied with regard to sun angle.) The distance between two successive polar orbits on the equator (for an 80 n.m. orbit) is approximately 1°. For an inclined orbit it is 1° x sin (inclination). An inclined orbit will enable CSM science at a wide range of sun angles, a polar mission would be much more restricted.

## CONCLUSIONS

Fourteen-day CSM orbital missions in conjunction with LPM landings are possible. With some modifications, polar orbits of the same duration may be used. Extensive coverage of the moon is available with almost no extra cost.

2015-IS-acm

I. Silberstein

Attachments
- References
- Table I
- Figures 1-16
- Appendix

## REFERENCES

1. "Site Accessibility Analysis for Advanced Lunar Missions", TRW Note No. 67-FMT-521.

2. "Quarterly Weight and Performance Report January 68 - March 68 (U)", NASA Document SE-15-002-1, page 11.

3. "CSM Requirements for Extended Lunar Missions", Bellcomm Technical Memorandum 67-1012-7, D. R. Valley, June 22, 1967.

TABLE I

LOI $\Delta V$ LIMIT*

| INCLINATION | CONFIGURATION 1 LOI $\Delta V$ | CONFIGURATION 1 TE $\Delta V$ | CONFIGURATION 2 LOI $\Delta V$ | CONFIGURATION 2 TE $\Delta V$ |
|---|---|---|---|---|
| 17** | 3350 | 3350 | -- | -- |
| 28** | -- | -- | 3740 | 3740 |
| 30 | 3100 | 3800 | 3100 | 3800 |
| 45 | 2950 | 4050 | 3550 | 4050 |
| 60 | 2850 | 4220 | 3450 | 4220 |
| 75 | 2820 | 4360 | 3480 | 4360 |
| 90 | 2750 | 4430 | 3320 | 4430 |

* $\Delta V$ does not include the 100 fps allowed for each midcourse correction

** Any ascending node longitude is permissible for CSM orbits whose inclination is lower than the ** number.

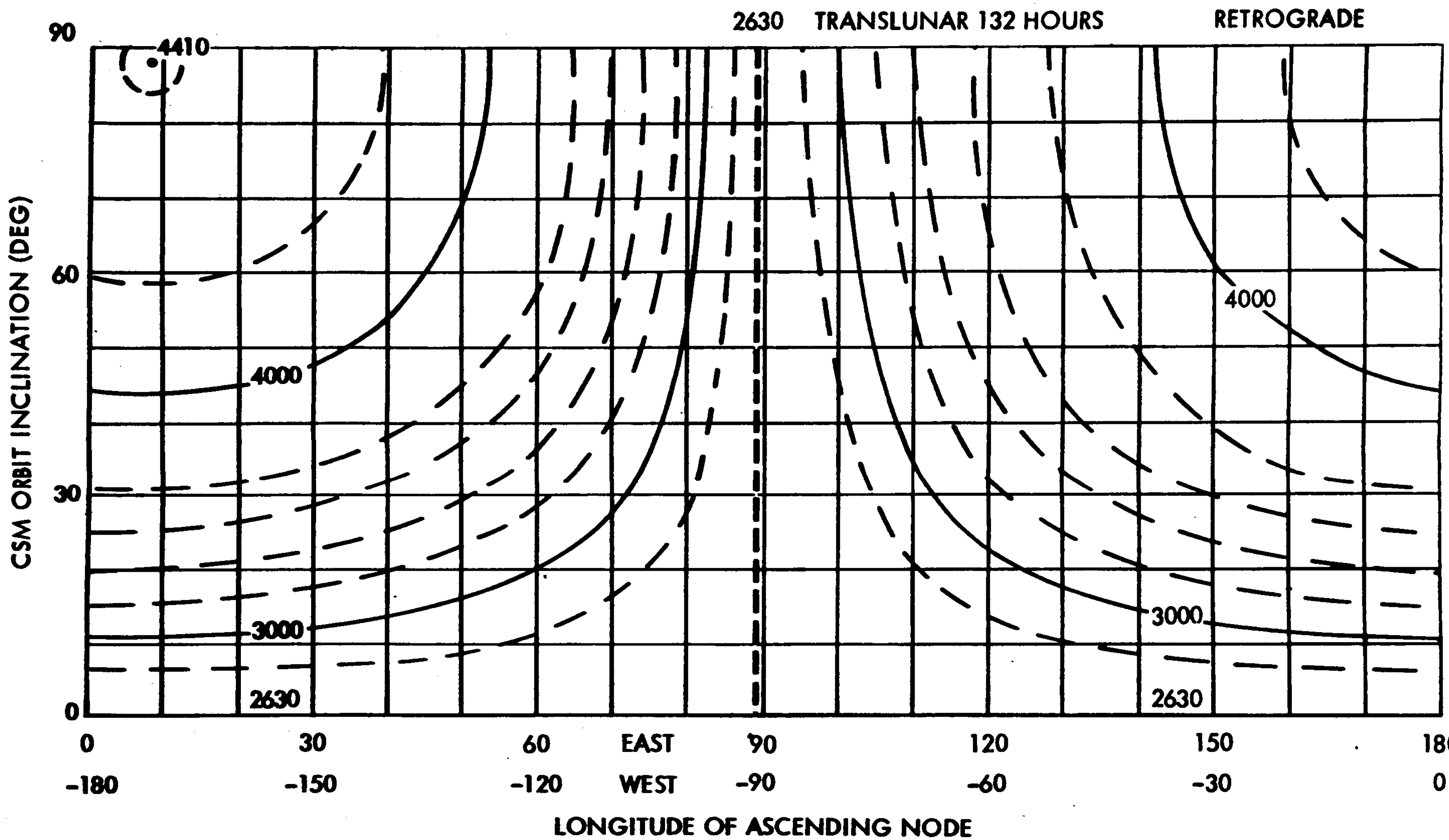



FIGURE 1 - TRANSLUNAR $\Delta V$ REQUIREMENTS; 132-HOUR FLIGHT TIME

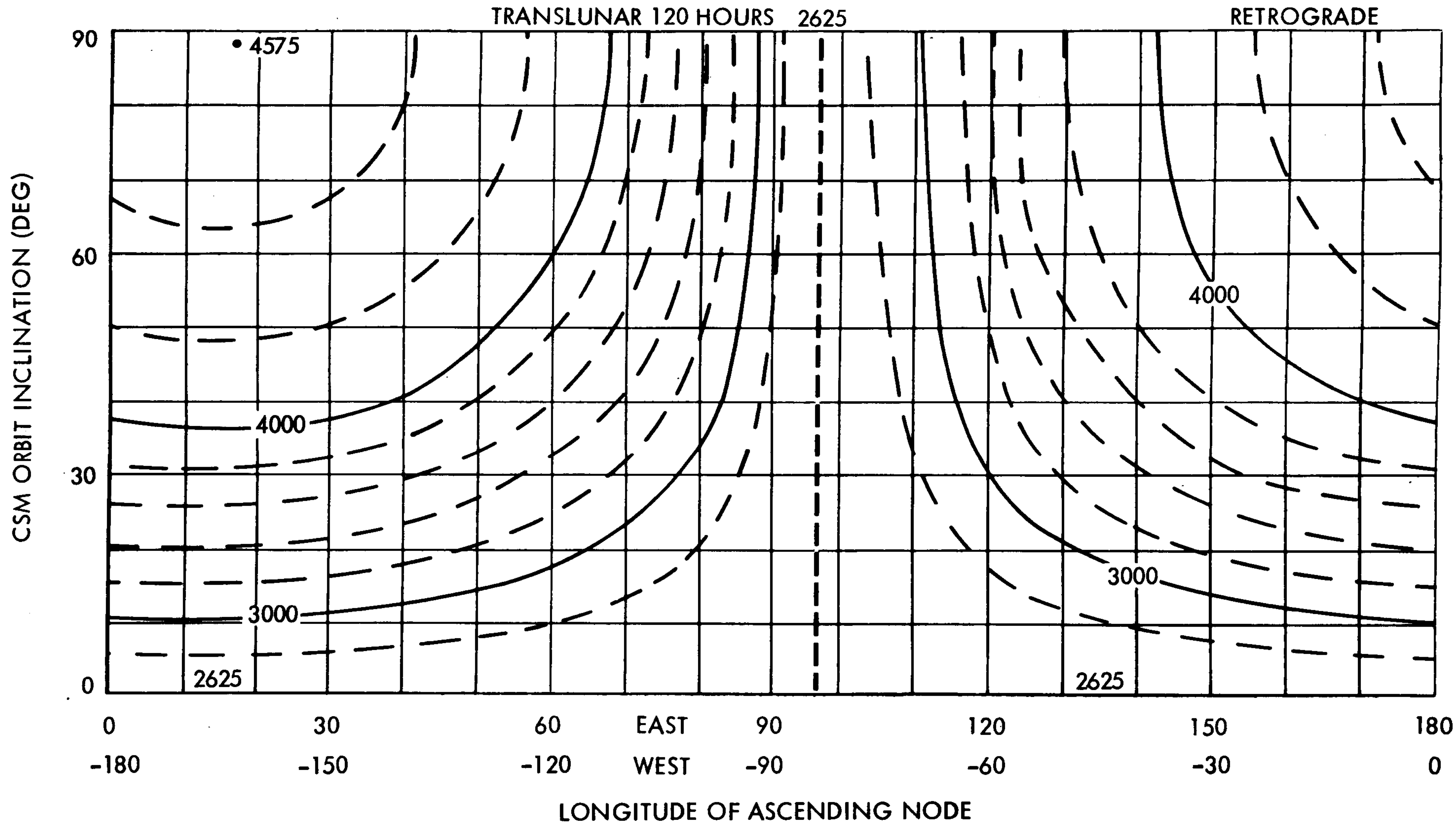



FIGURE 2 - TRANSLUNAR $\Delta$ V REQUIREMENTS; 120-HOUR FLIGHT TIME

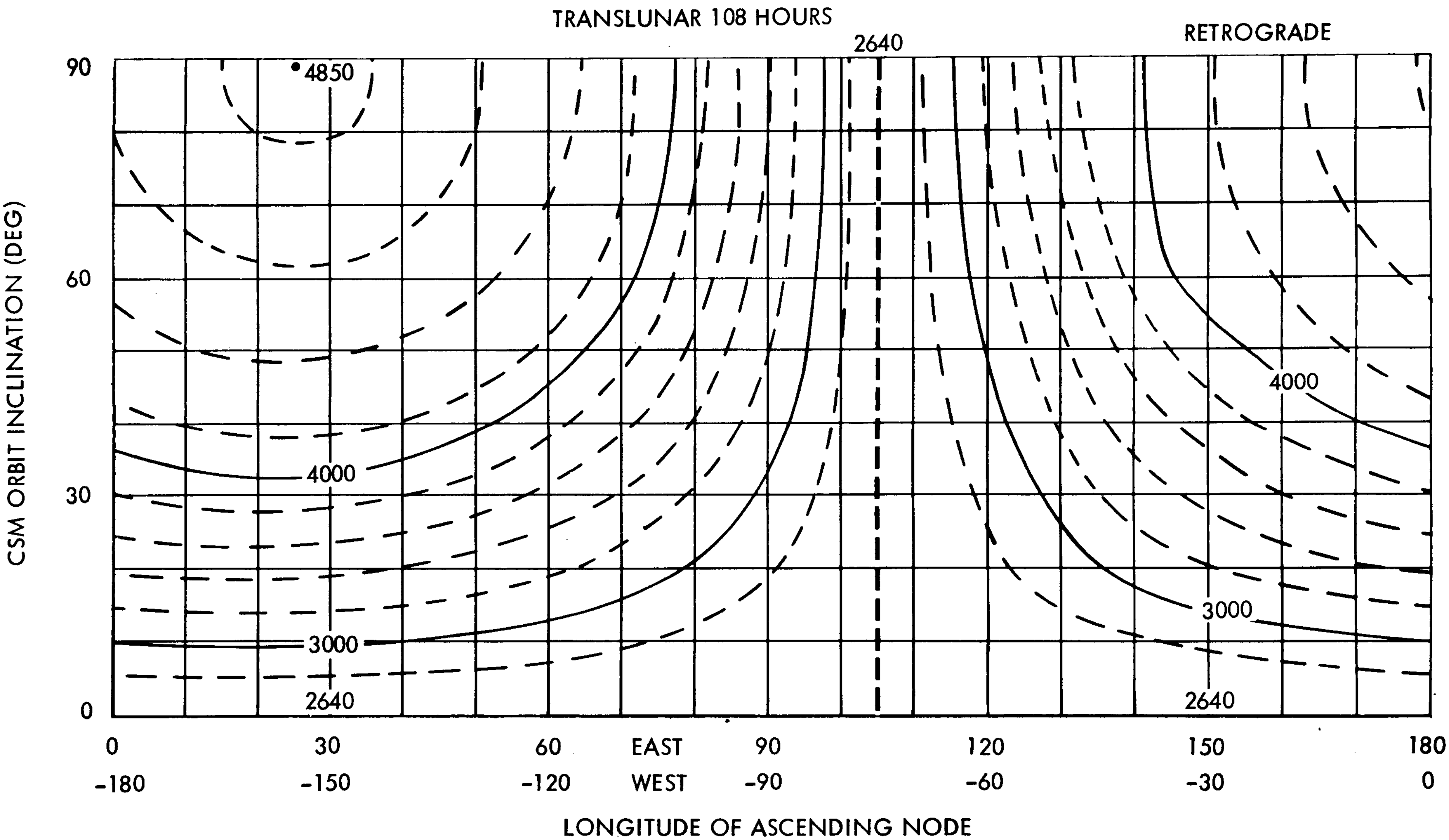



FIGURE 3 - TRANSLUNAR $\Delta$ V REQUIREMENTS; 108-HOUR FLIGHT TIME

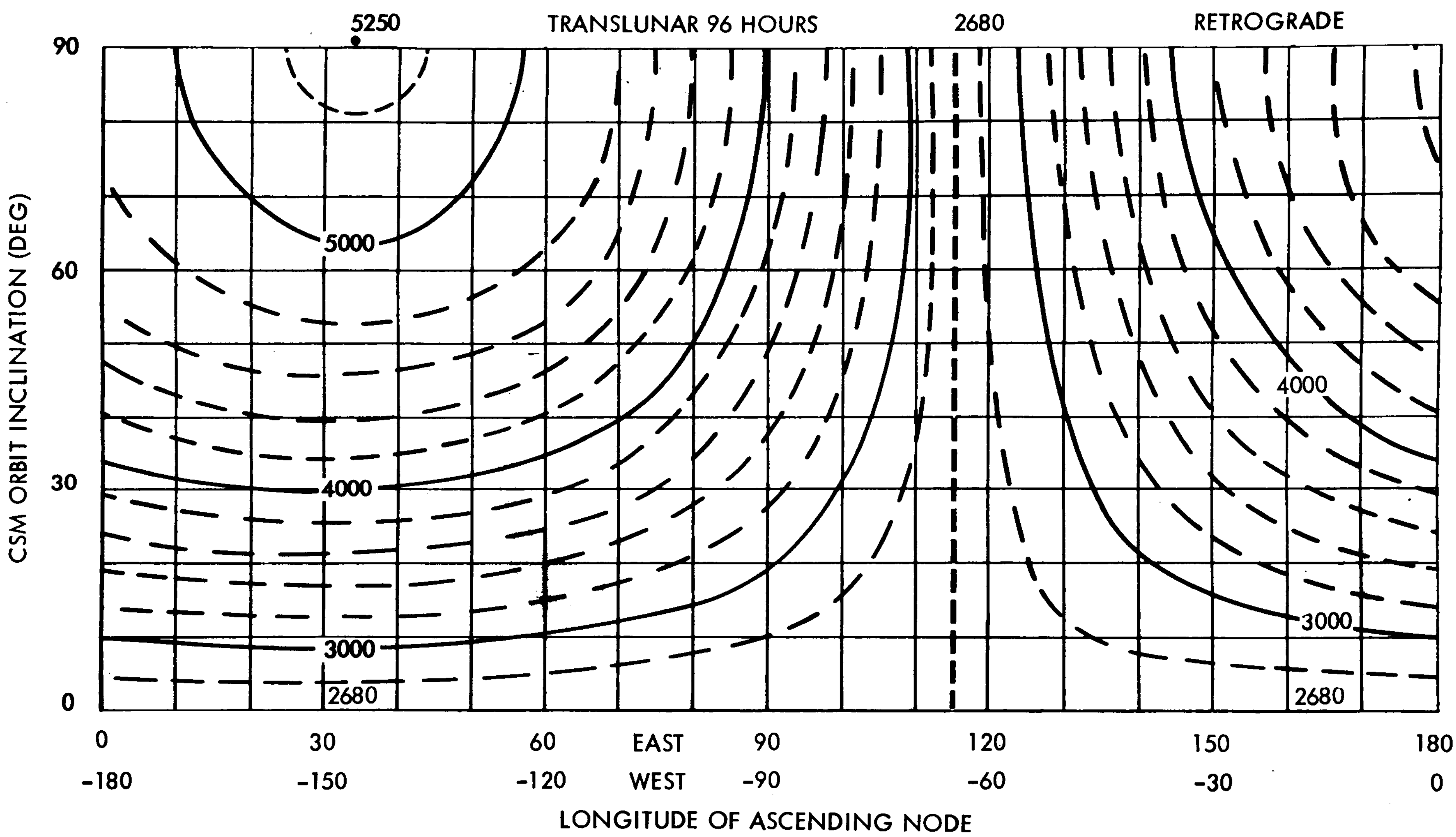



FIGURE 4 - TRANSLUNAR $\Delta$ V REQUIREMENTS; 96-HOUR FLIGHT TIME

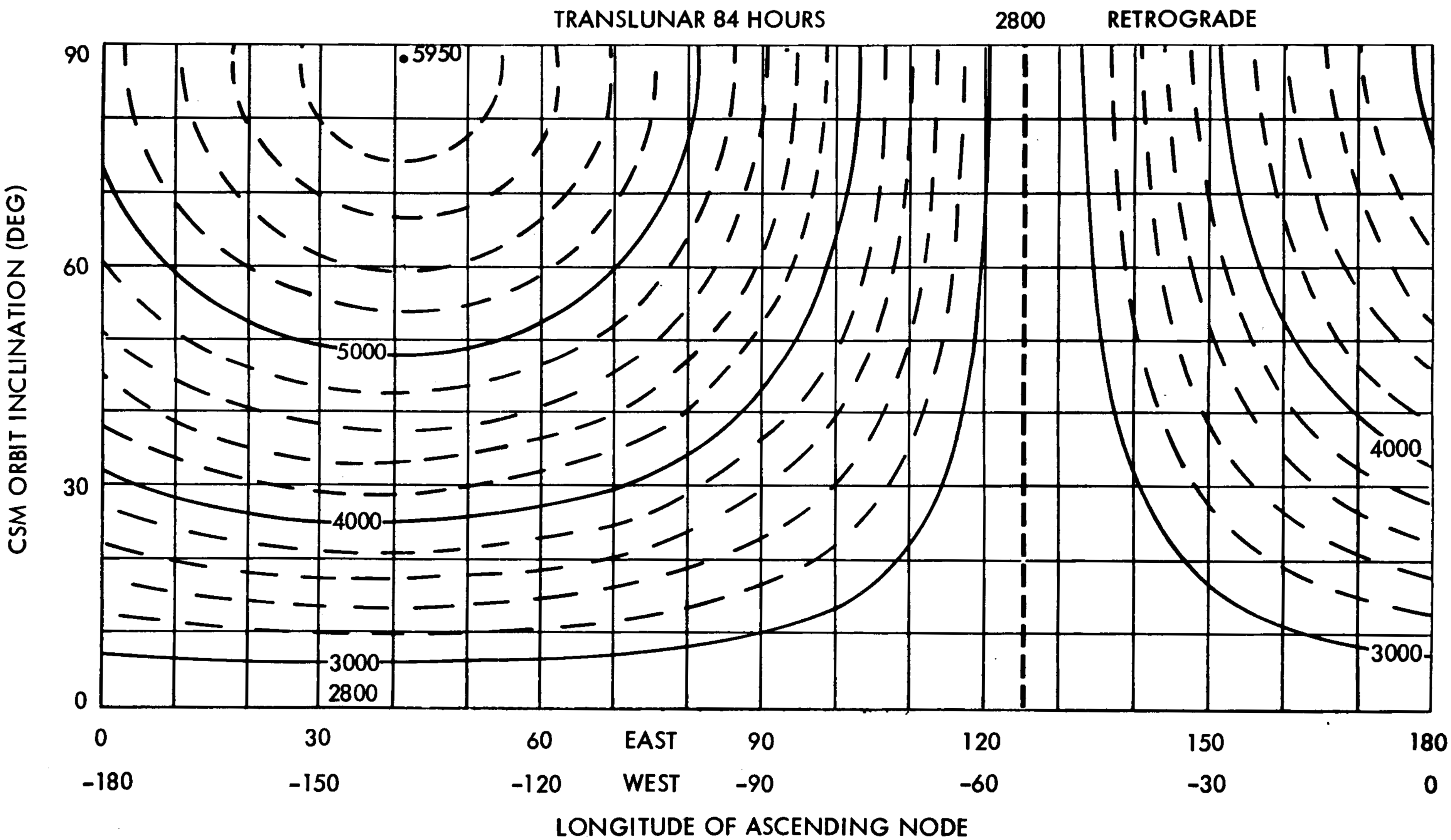



FIGURE 5 - TRANSLUNAR $\Delta V$ REQUIREMENTS; 84-HOUR FLIGHT TIME

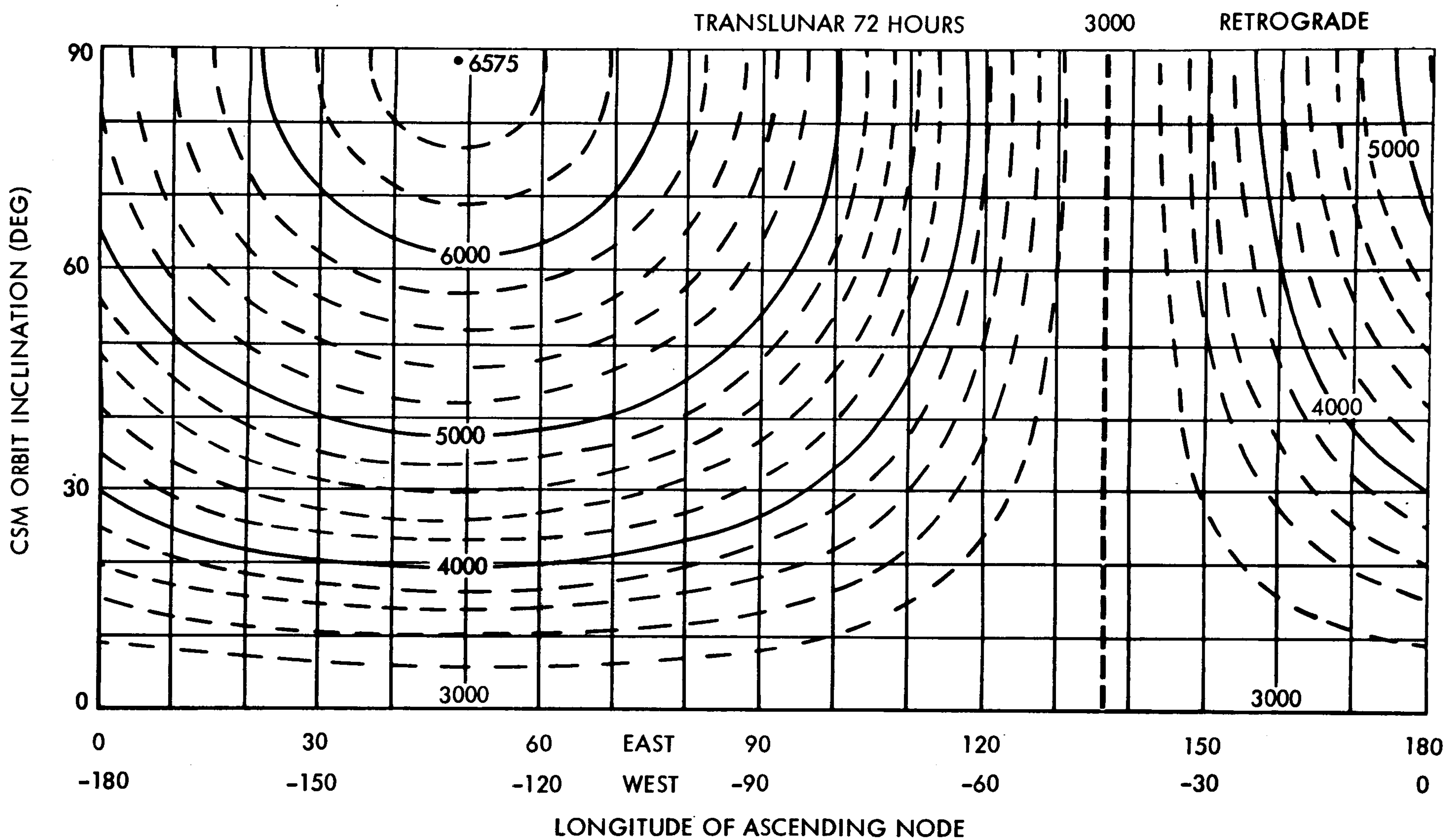



FIGURE 6 - TRANSLUNAR $\Delta$V REQUIREMENTS; 72-HOUR FLIGHT TIME

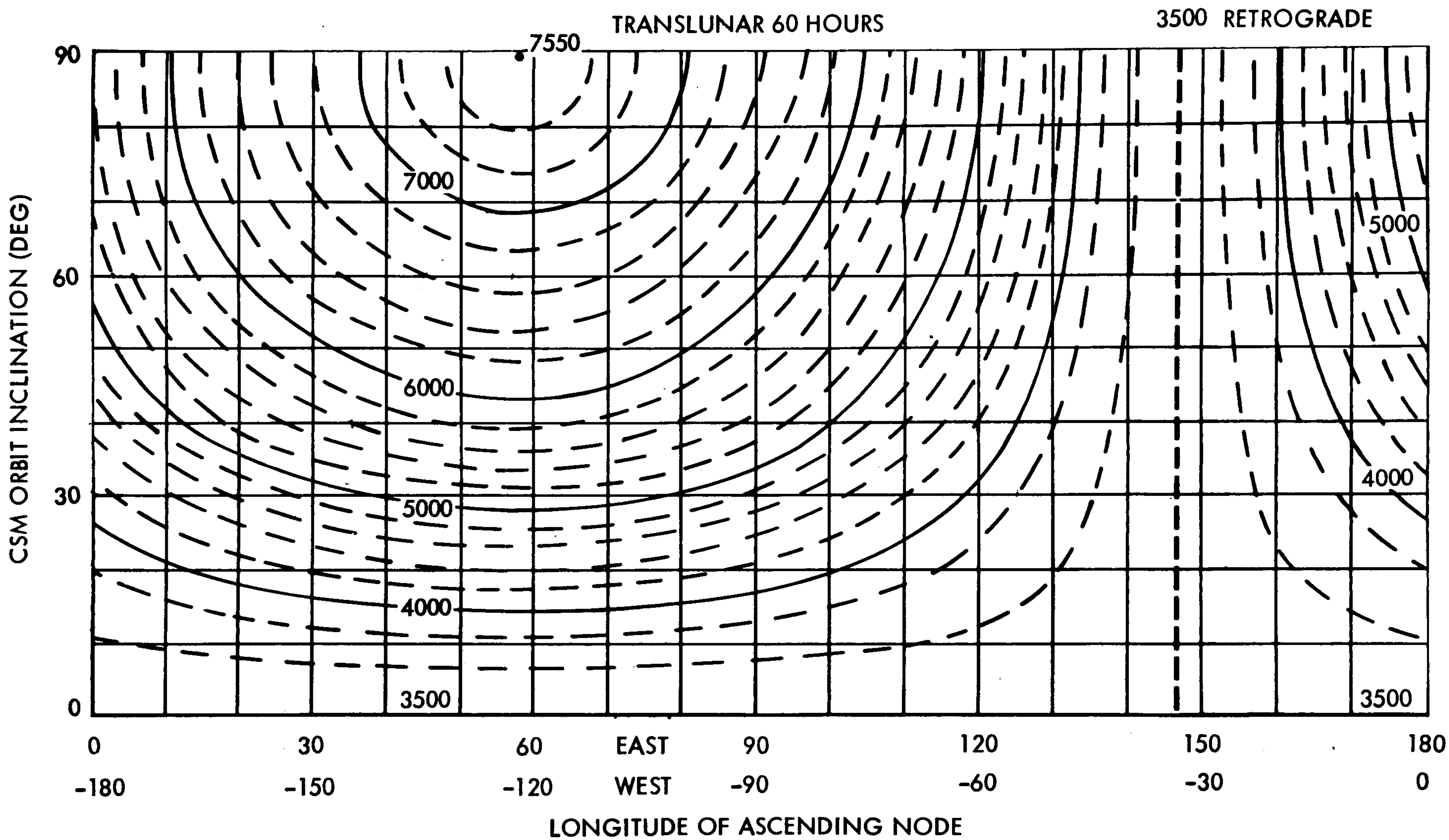



FIGURE 7 - TRANSLUNAR $\Delta$ V REQUIREMENTS; 60-HOUR FLIGHT TIME

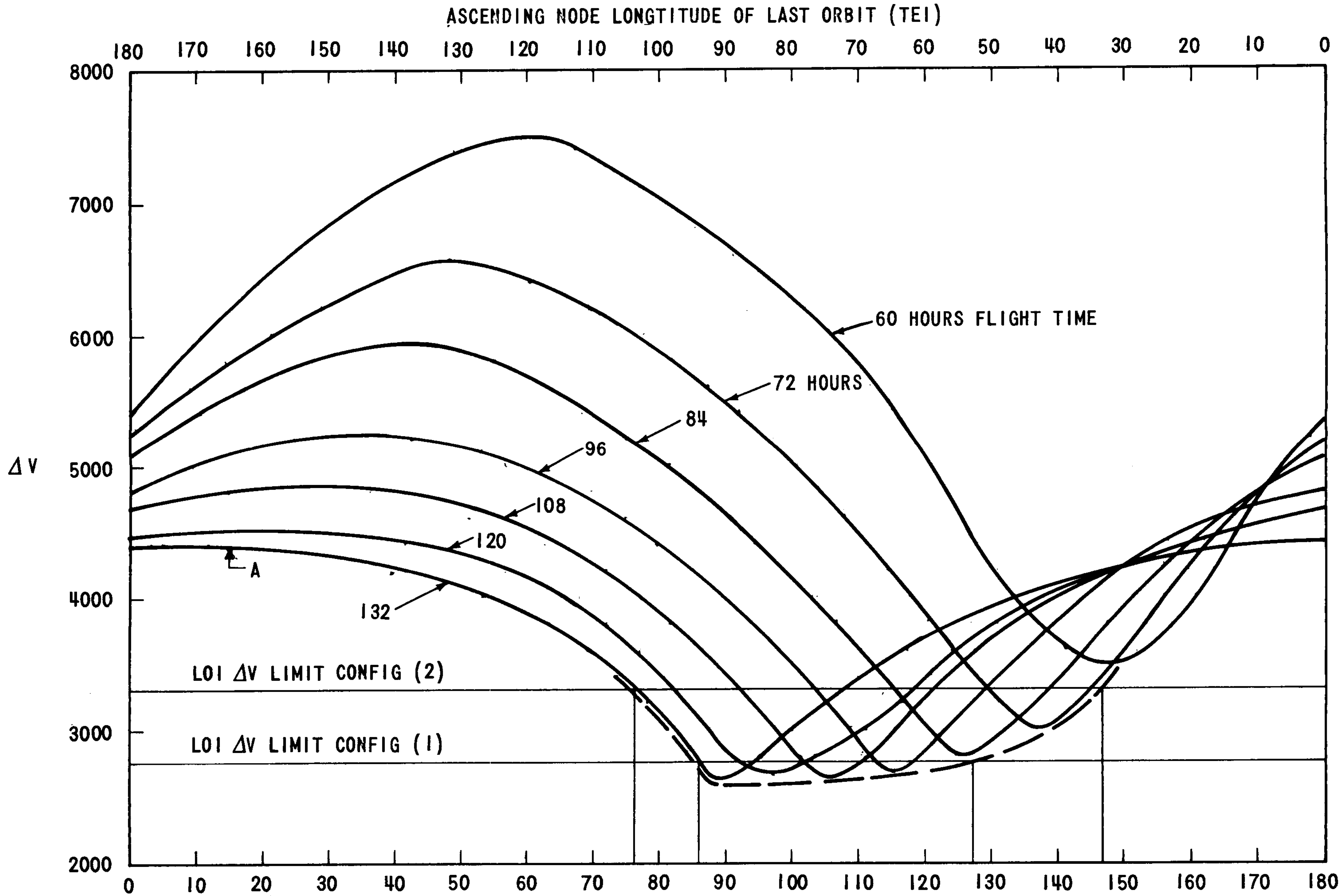



FIGURE 8 - ASCENDING NODE LONGTITUDE OF FIRST ORBIT 90° INCLINATION

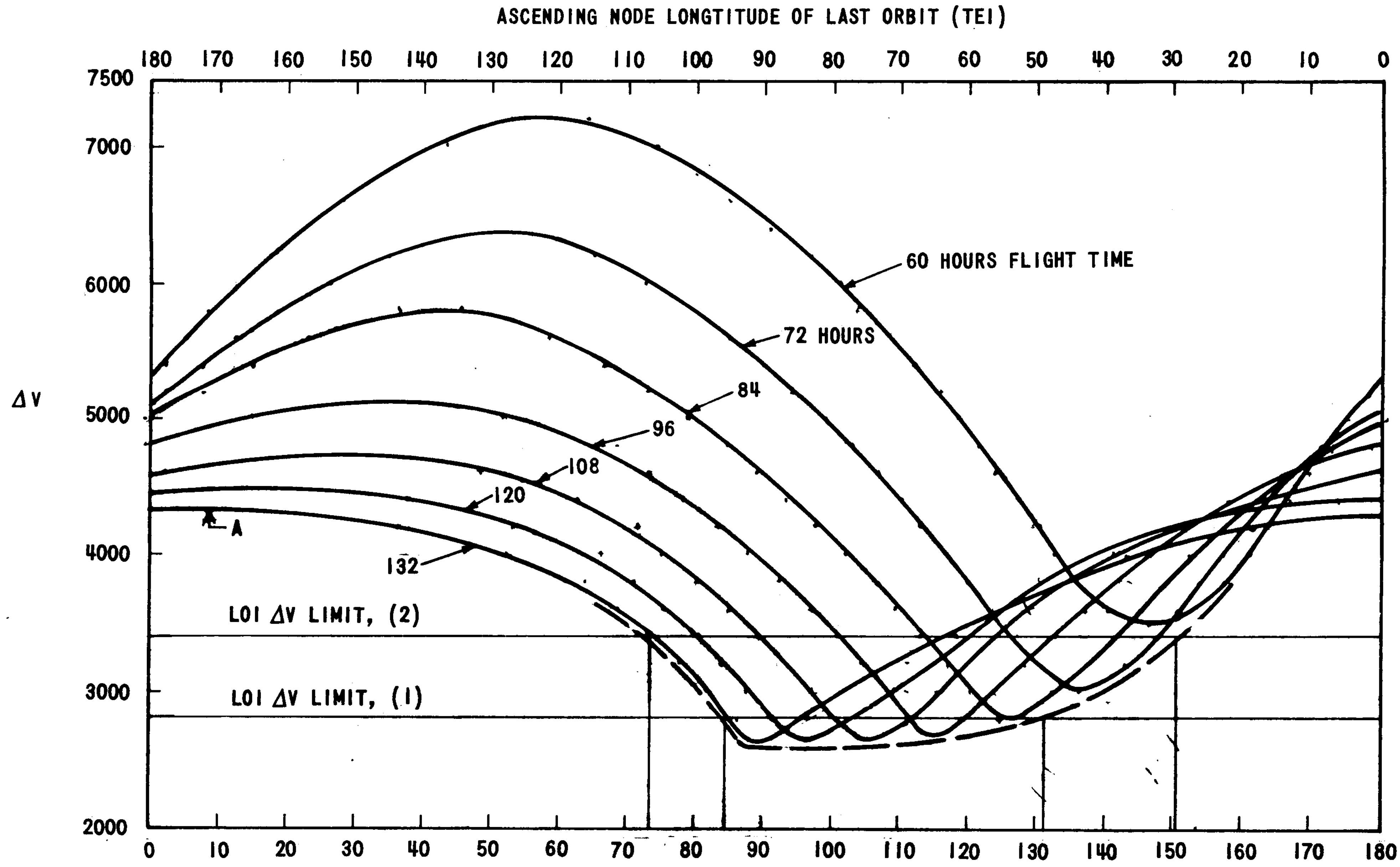



FIGURE 9 - ASCENDING NODE LONGTITUDE OF FIRST ORBIT 75° INCLINATION

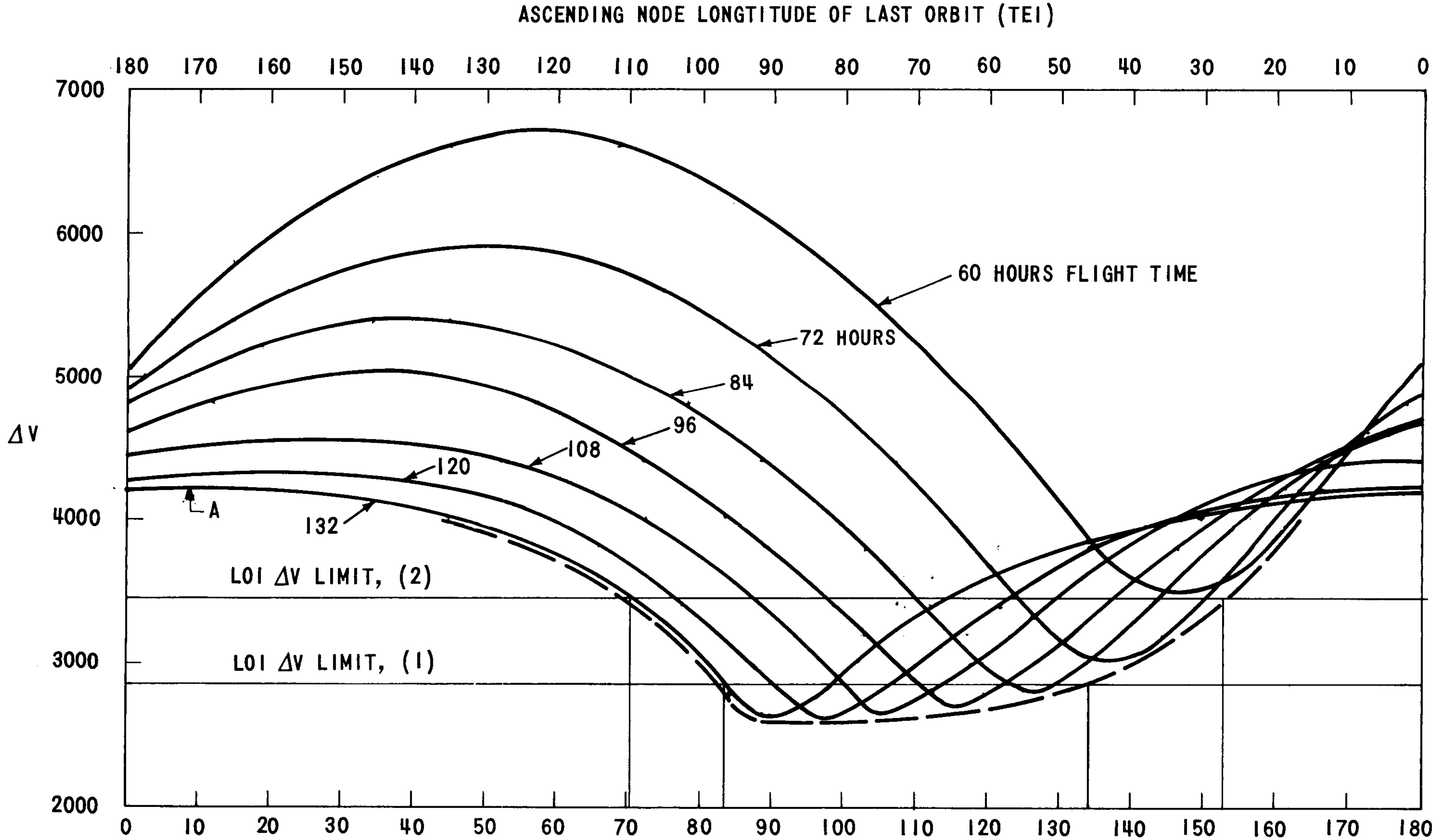



FIGURE 10 - ASCENDING NODE LONGTITUDE OF FIRST ORBIT 60° INCLINATION

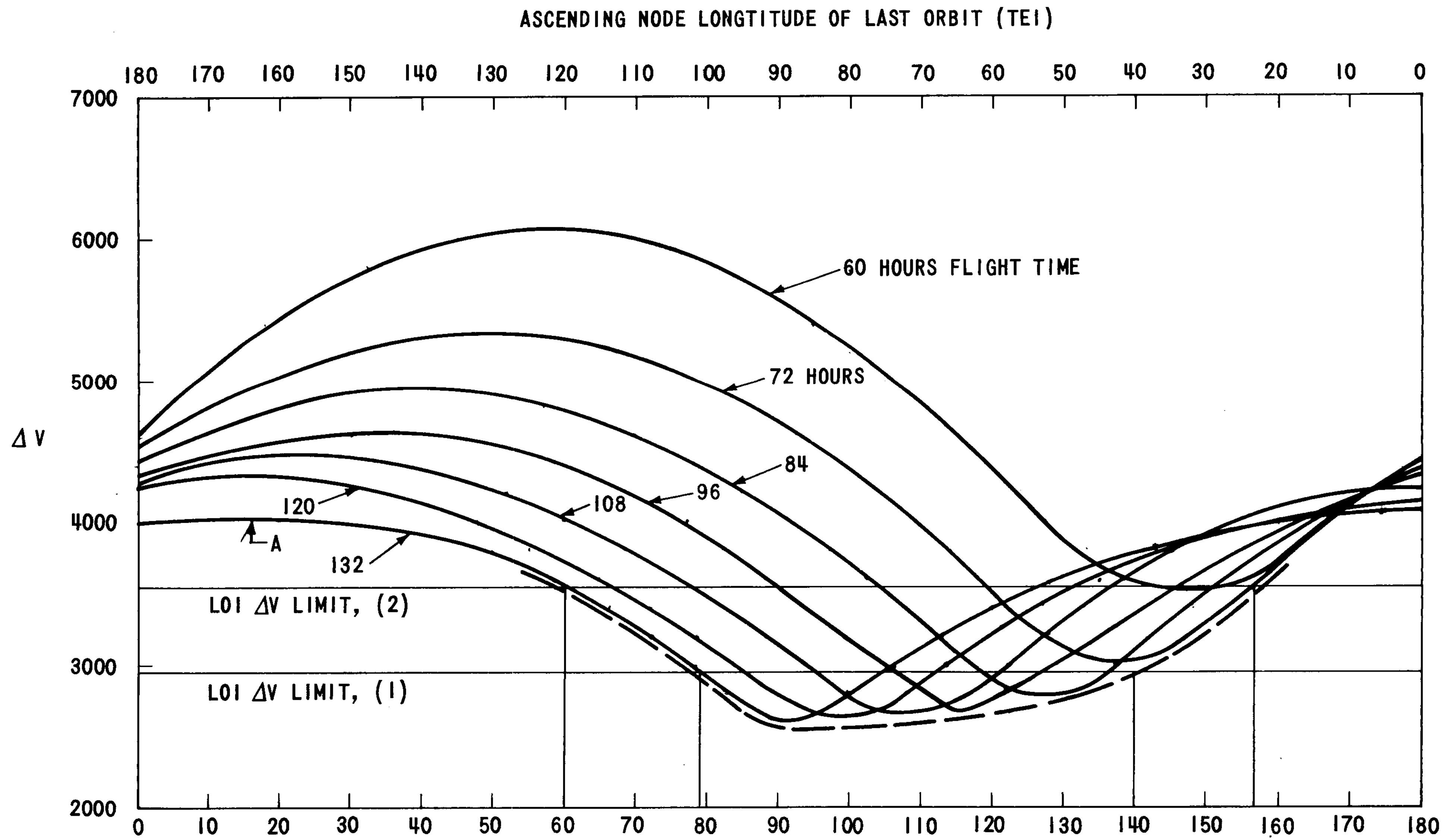



FIGURE 11 - ASCENDING NODE LONGTITUDE OF FIRST ORBIT 45° INCLINATION

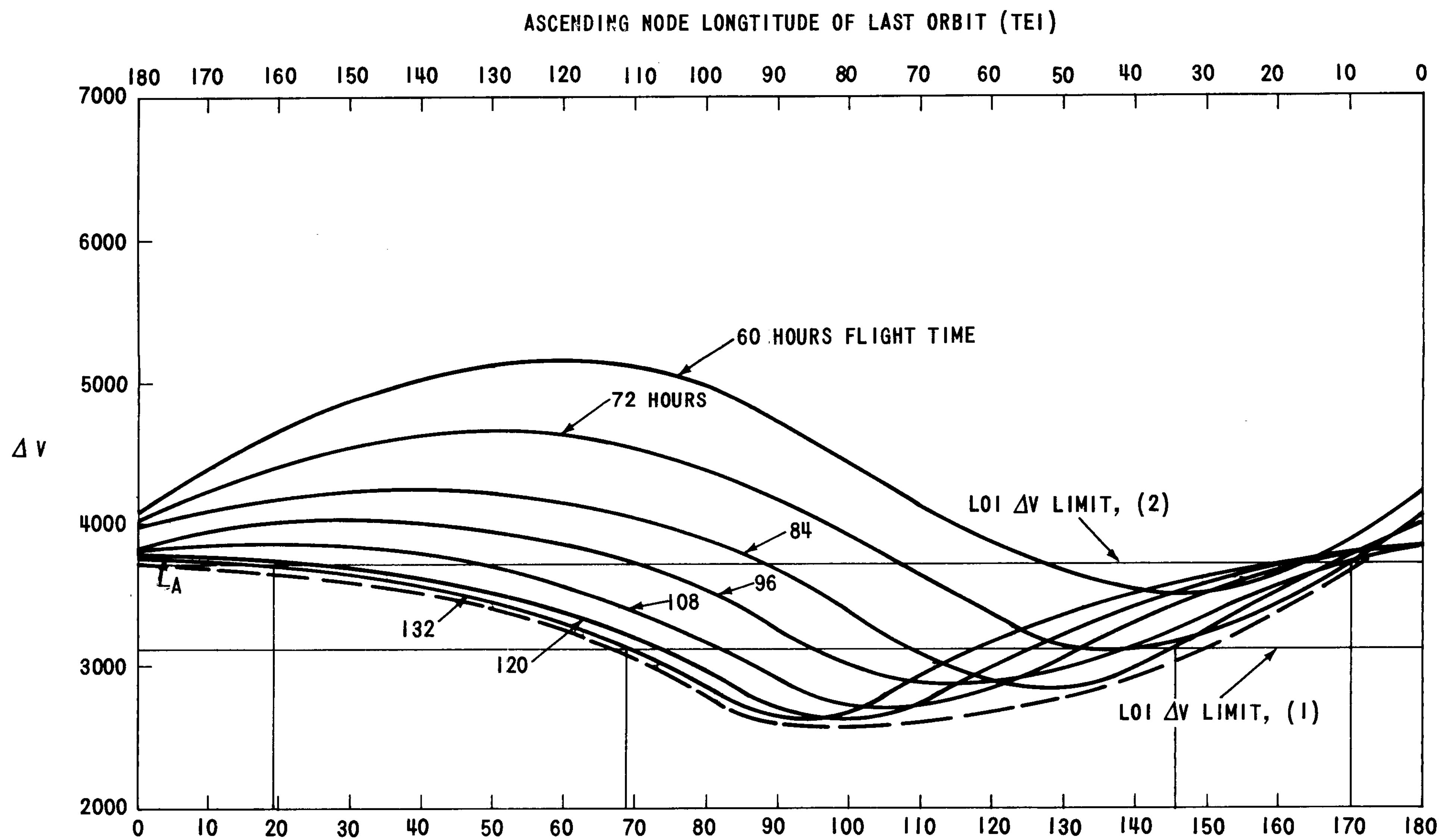



FIGURE 12 - ASCENDING NODE LONGTITUDE OF FIRST ORBIT 30° INCLINATION

CONFIGURATION I - MERCATOR PROJECTION OF AREAS ACCESSIBLE TO LPM WHEN CSM ORBIT INCLINATION IS 90°

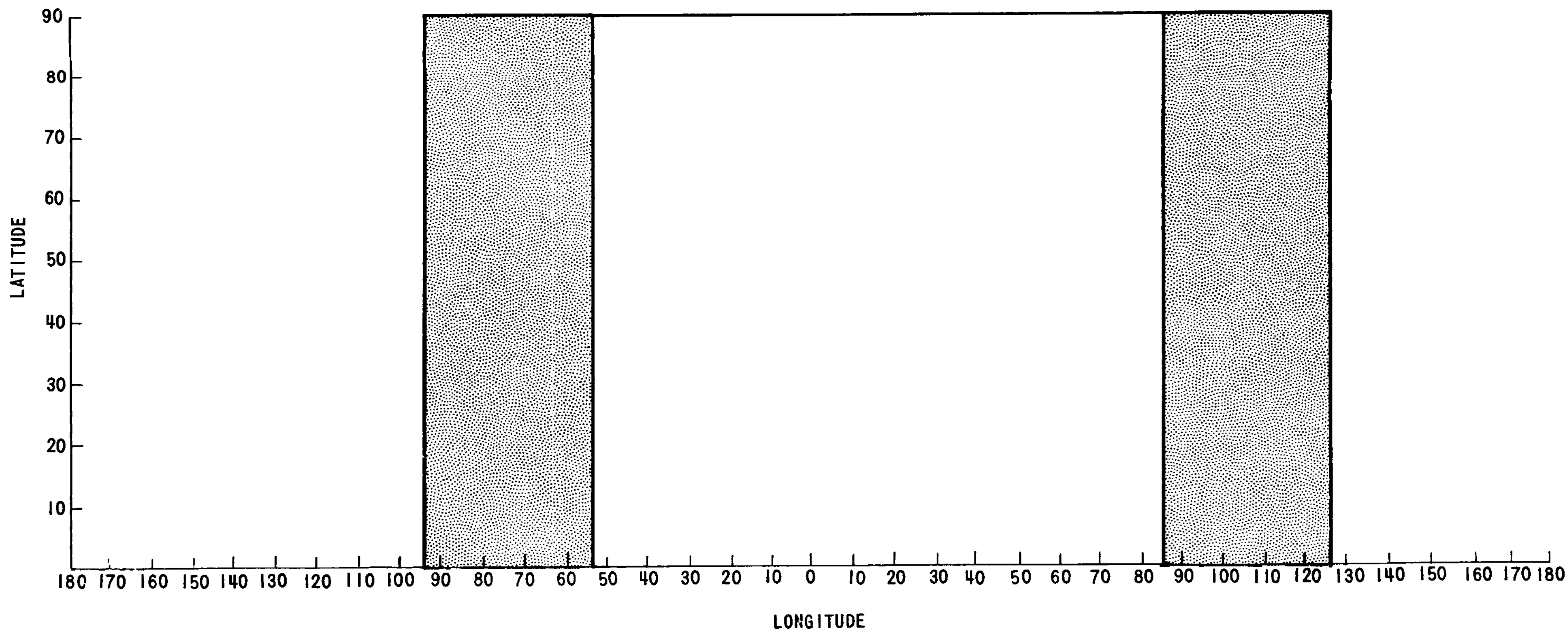



FIGURE 13A

CONFIGURATION I - MERCATOR PROJECTION OF AREAS ACCESSIBLE TO LPM WHEN CSM ORBIT INCLINATION IS 75°

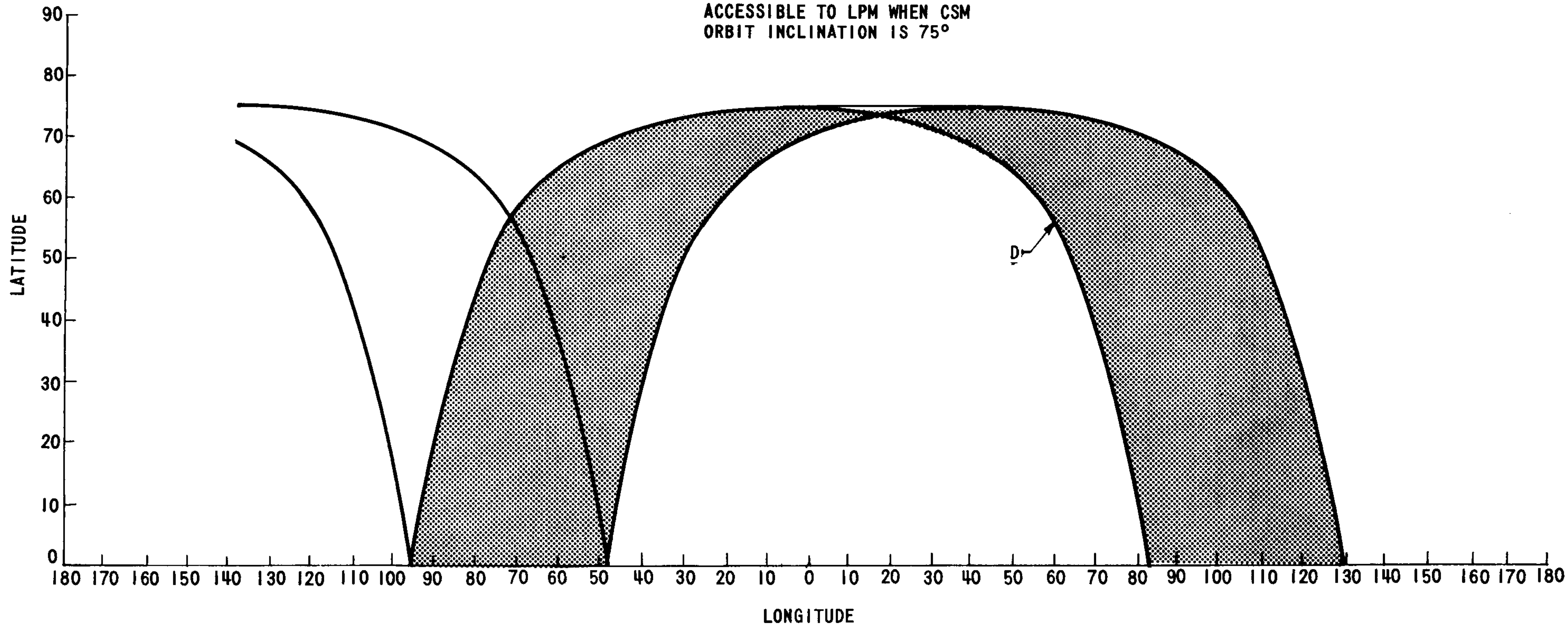



FIGURE 13B

CONFIGURATION I - MERCATOR PROJECTION OF AREAS ACCESSIBLE TO LPM WHEN CSM ORBIT INCLINATION IS 60°

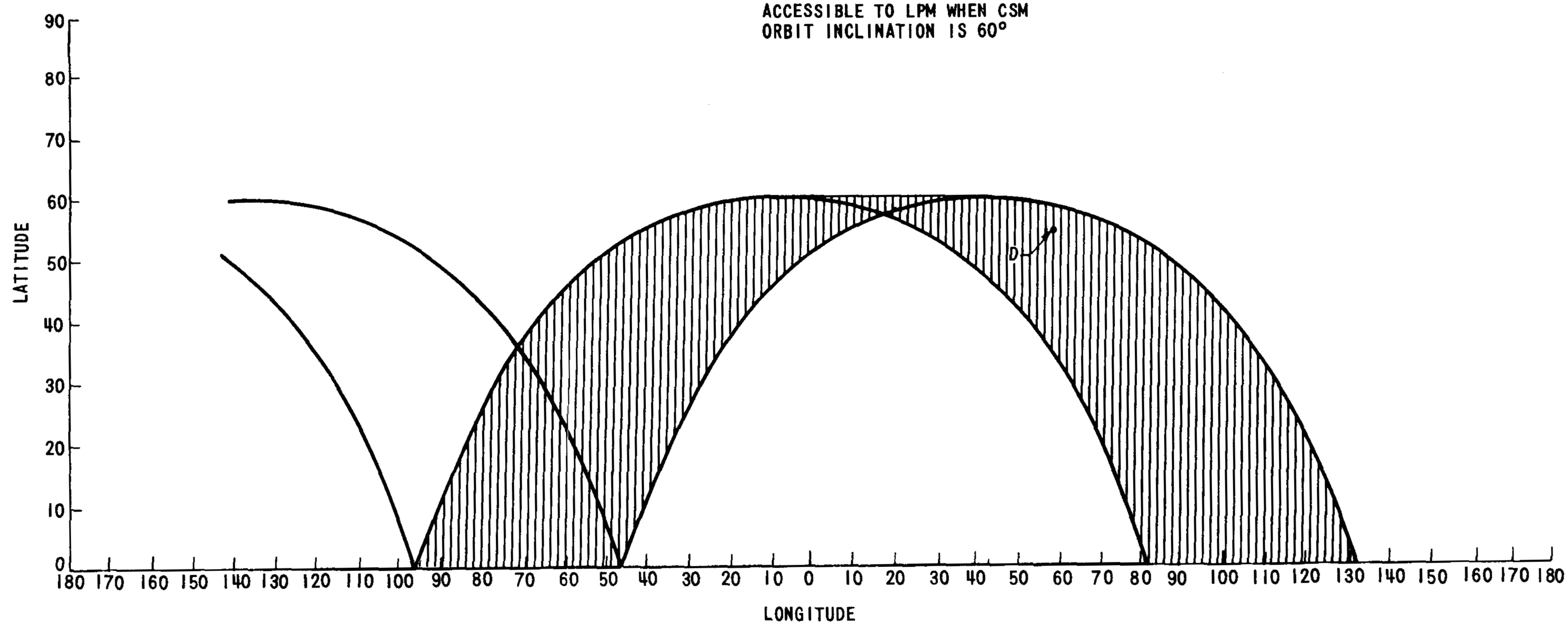



FIGURE 13C

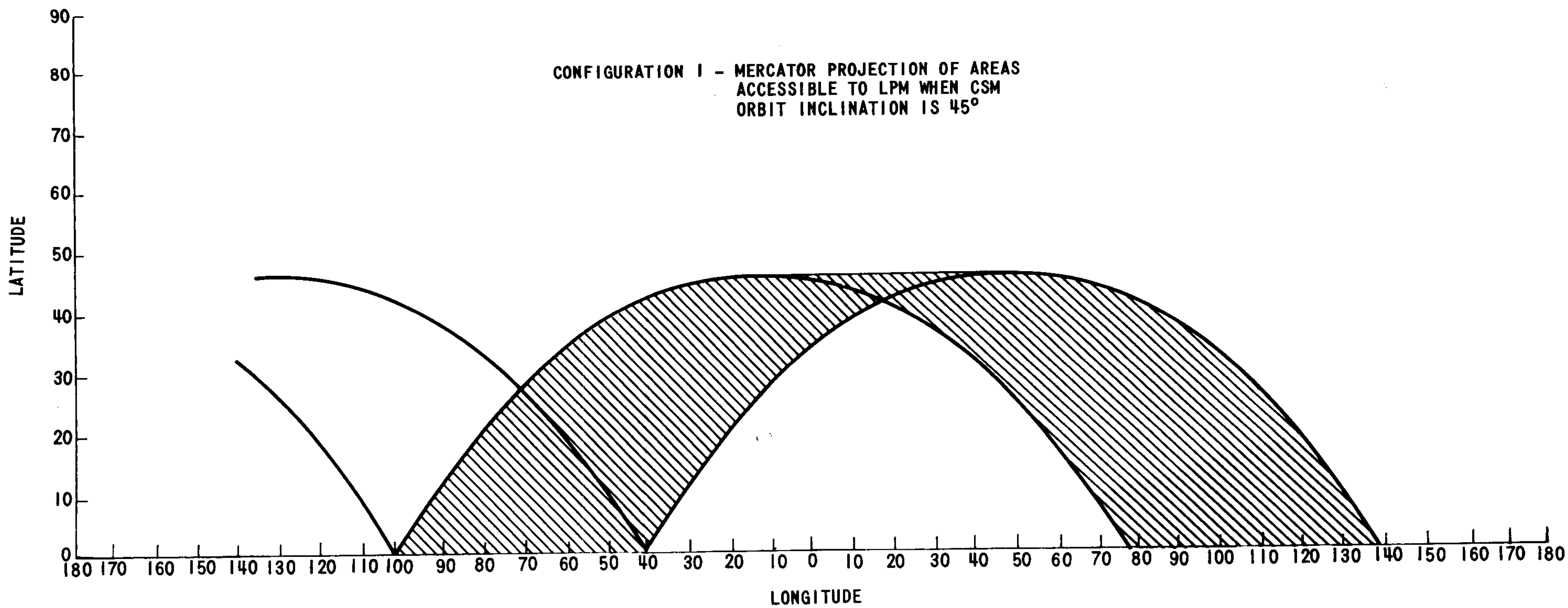
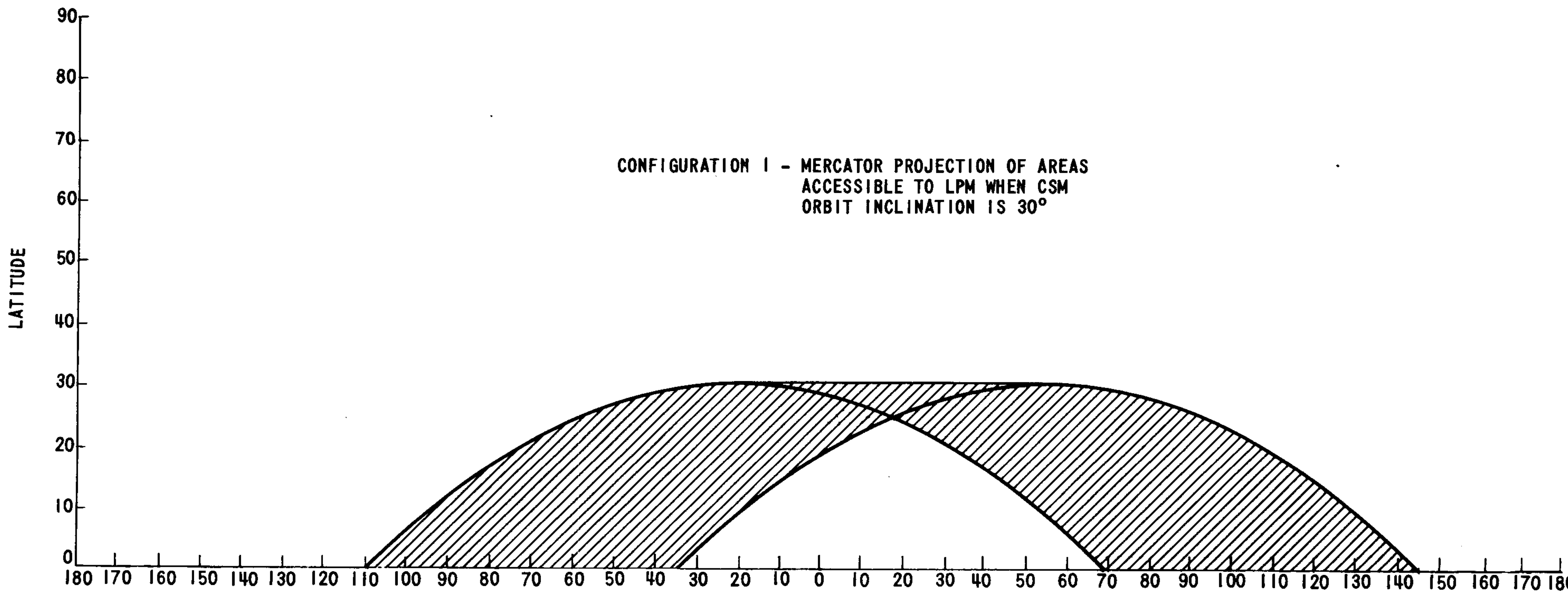

CONFIGURATION I - MERCATOR PROJECTION OF AREAS
ACCESSIBLE TO LPM WHEN CSM
ORBIT INCLINATION IS 45°
LATITUDE
90
80
70
60
50
40
30
20
10
0
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
LONGITUDE

FIGURE 13D


CONFIGURATION I - MERCATOR PROJECTION OF AREAS
ACCESSIBLE TO LPM WHEN CSM
ORBIT INCLINATION IS 30°
LATITUDE
90
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30
20
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0
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
LONGITUDE

FIGURE 13E

CONFIGURATION 2 - MERCATOR PROJECTION OF AREAS
ACCESSIBLE TO LPM WHEN CSM
ORBIT INCLINATION IS 90°

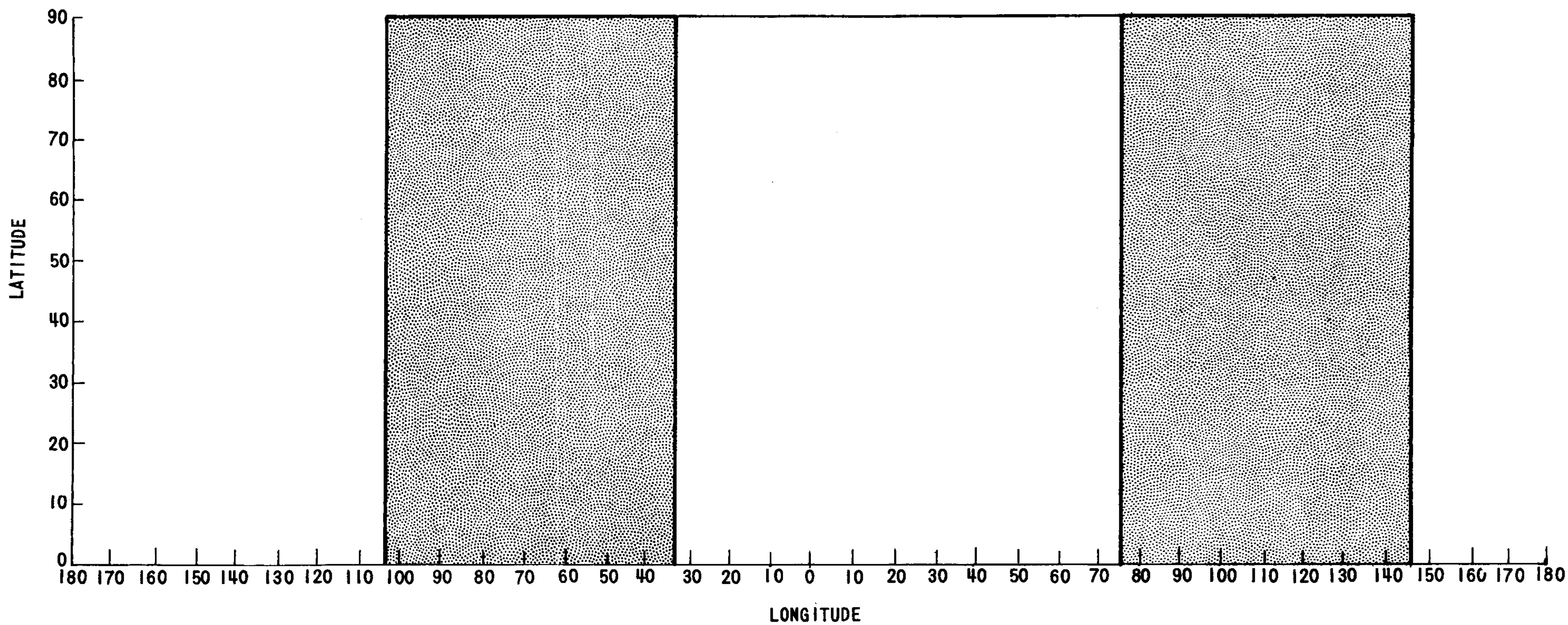



FIGURE 14A

CONFIGURATION 2 - MERCATOR PROJECTION OF AREAS ACCESSIBLE TO LPM WHEN CSM ORBIT INCLINATION 75°

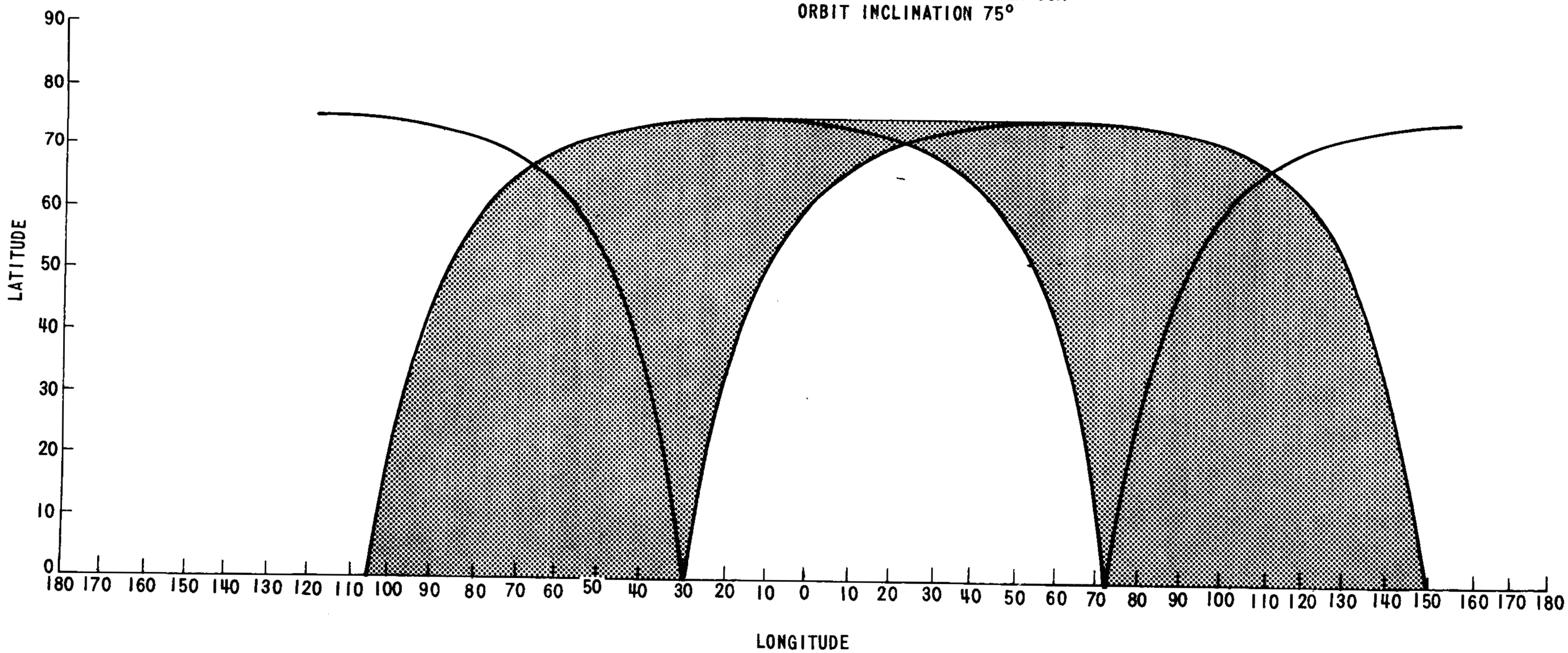



FIGURE 14B

CONFIGURATION 2 - MERCATOR PROJECTION OF AREAS ACCESSIBLE TO LPM WHEN CSM ORBIT INCLINATION IS 60°

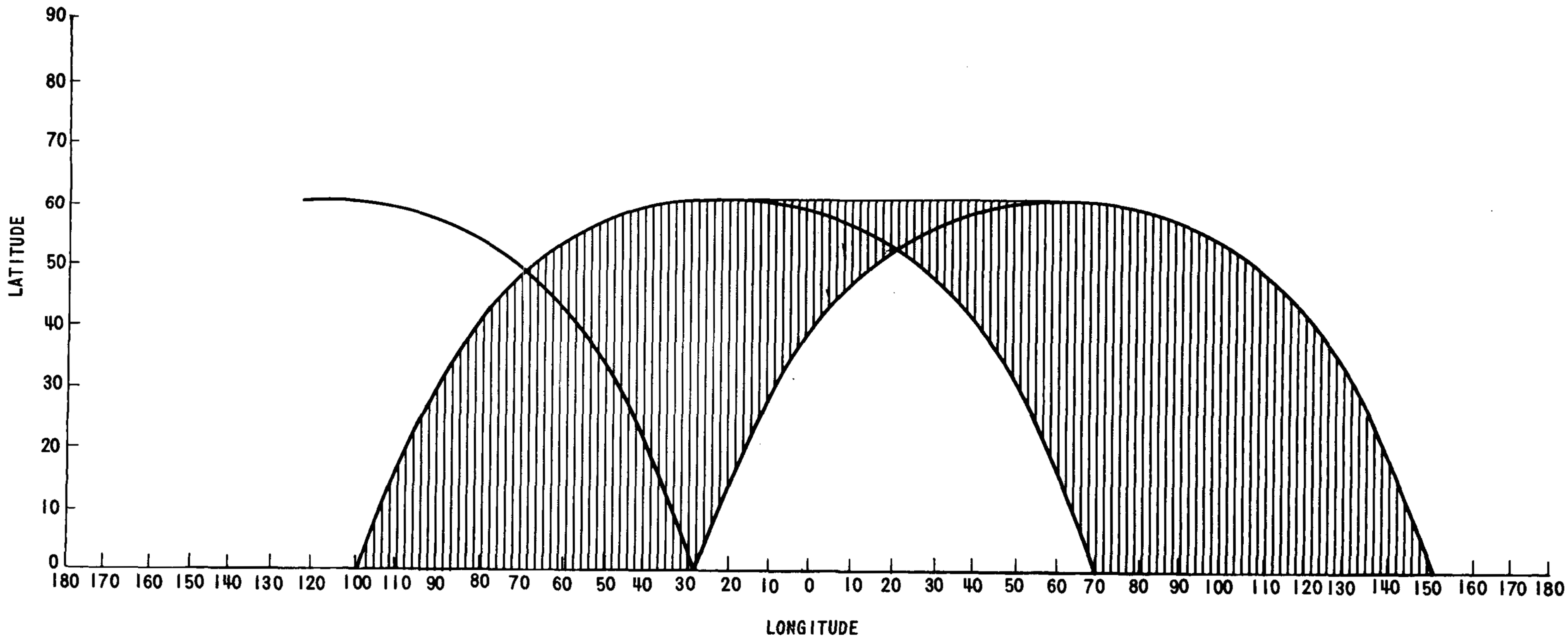



FIGURE 14C

CONFIGURATION 2 - MERCATOR PROJECTION OF AREAS ACCESSIBLE TO LPM WHEN CSM ORBIT INCLINATION 45°

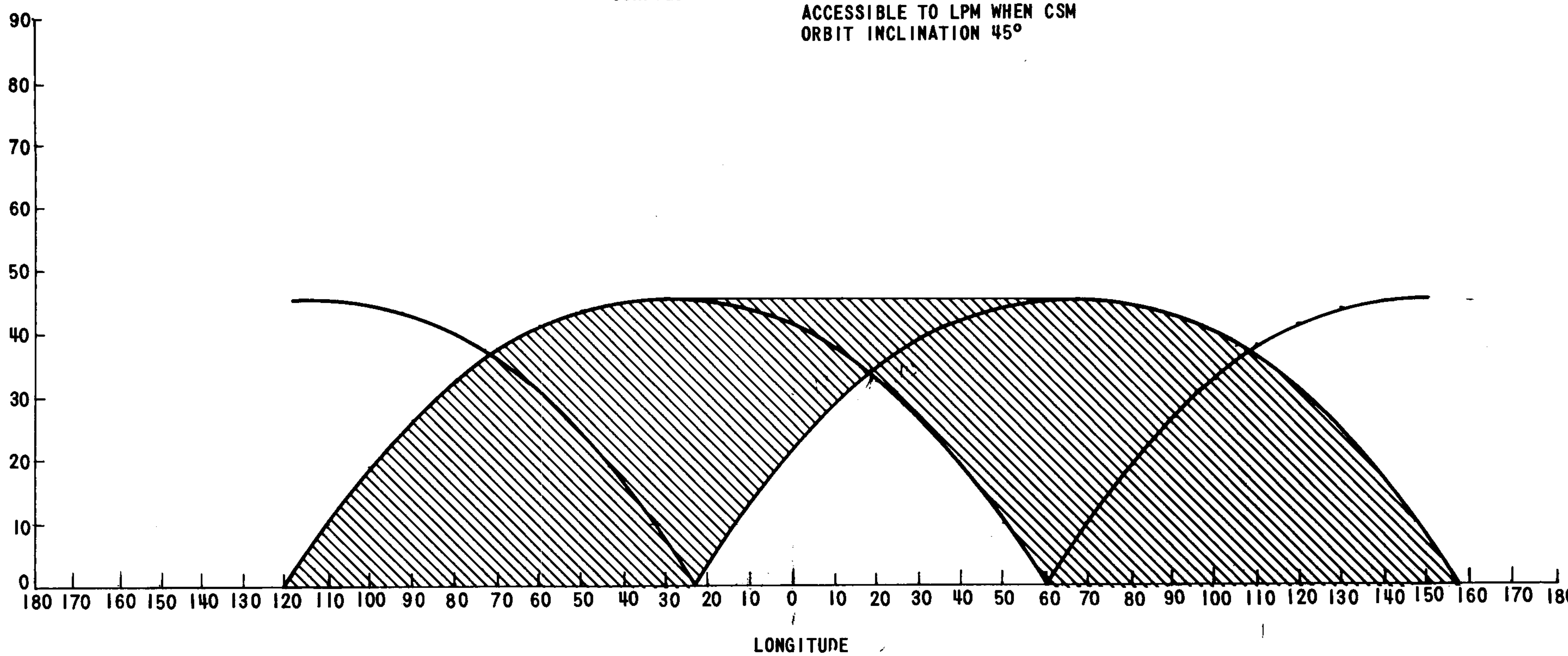
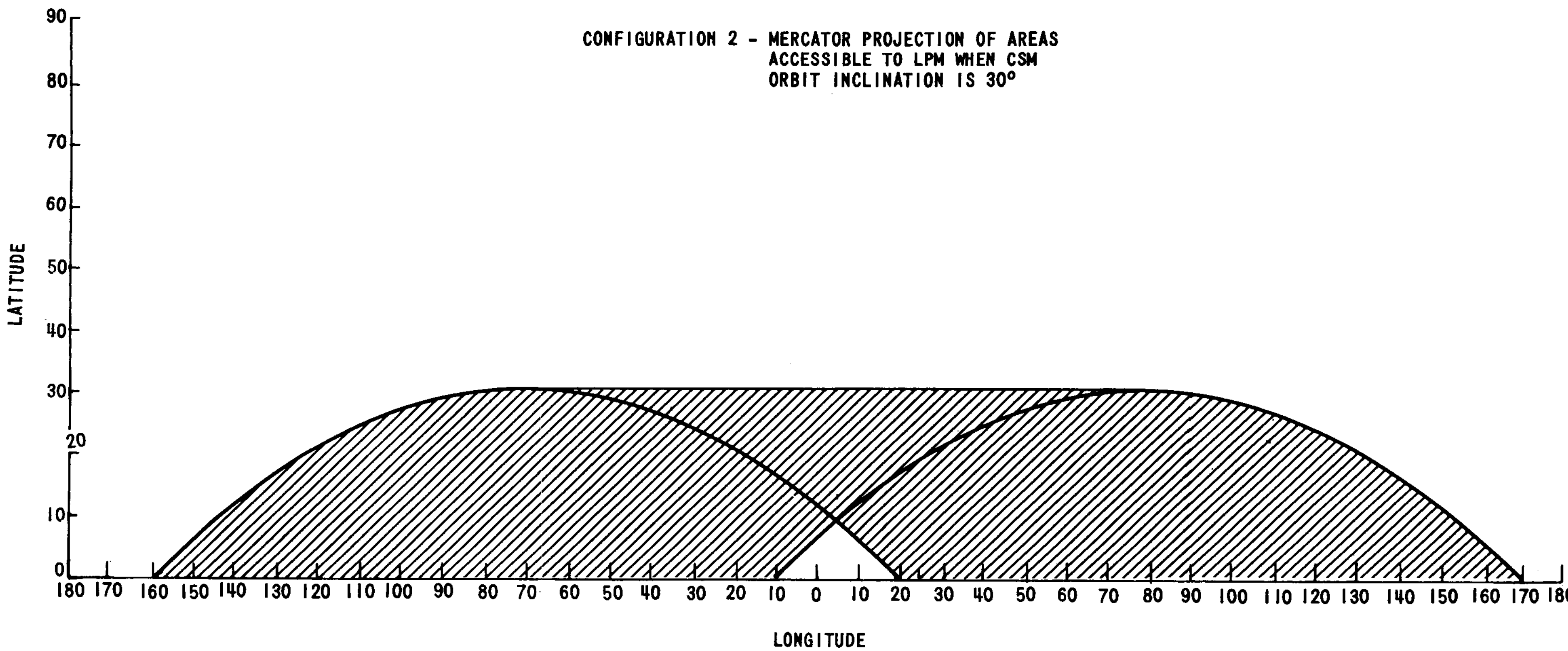



FIGURE 14D


CONFIGURATION 2 - MERCATOR PROJECTION OF AREAS ACCESSIBLE TO LPM WHEN CSM ORBIT INCLINATION IS 30°
LATITUDE
90
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180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
LONGITUDE

FIGURE 14E

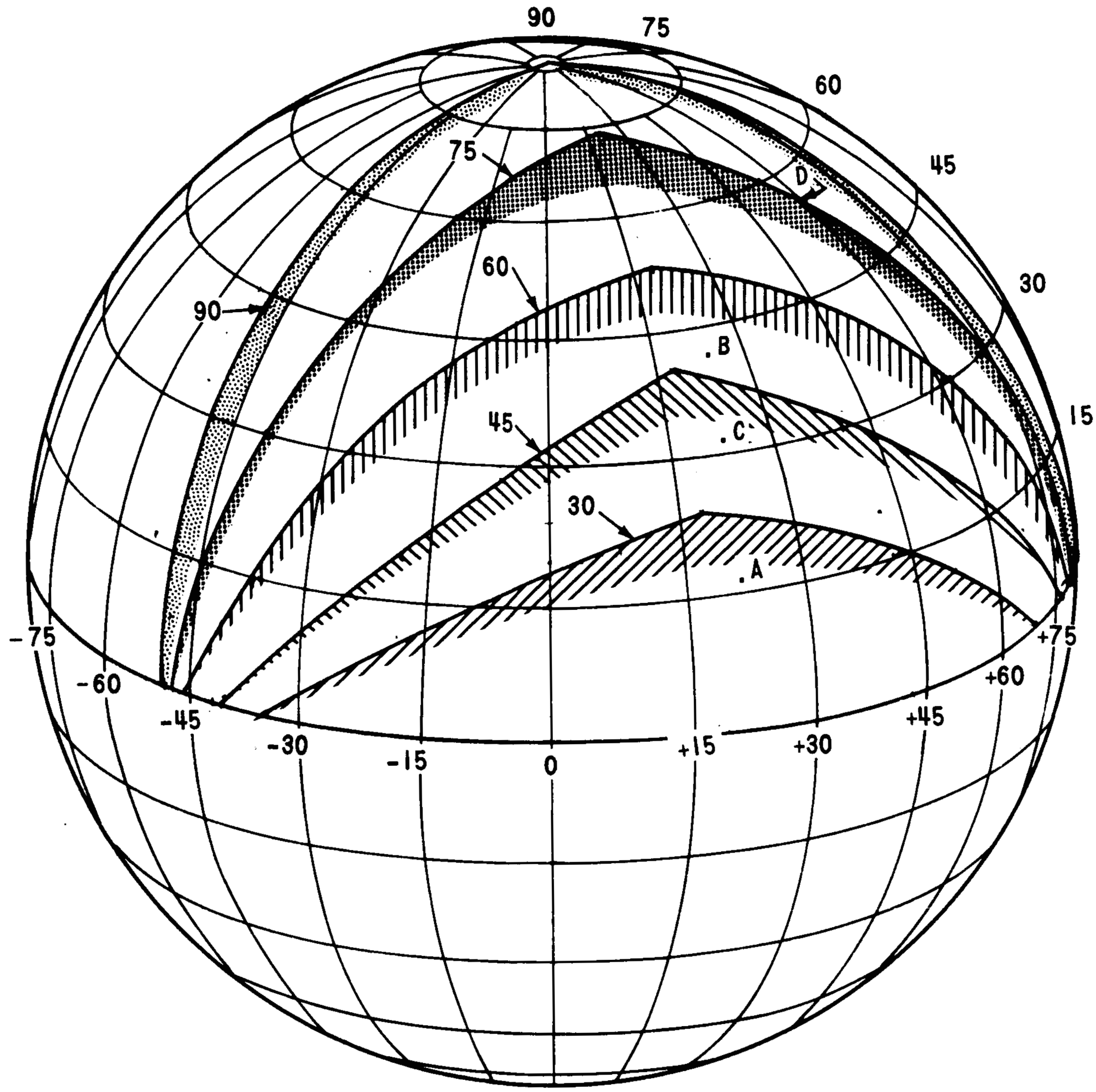


FIGURE 15 - RESTRICTIONS ON ACCESSIBILITY, CSM & LPM UNMODIFIED

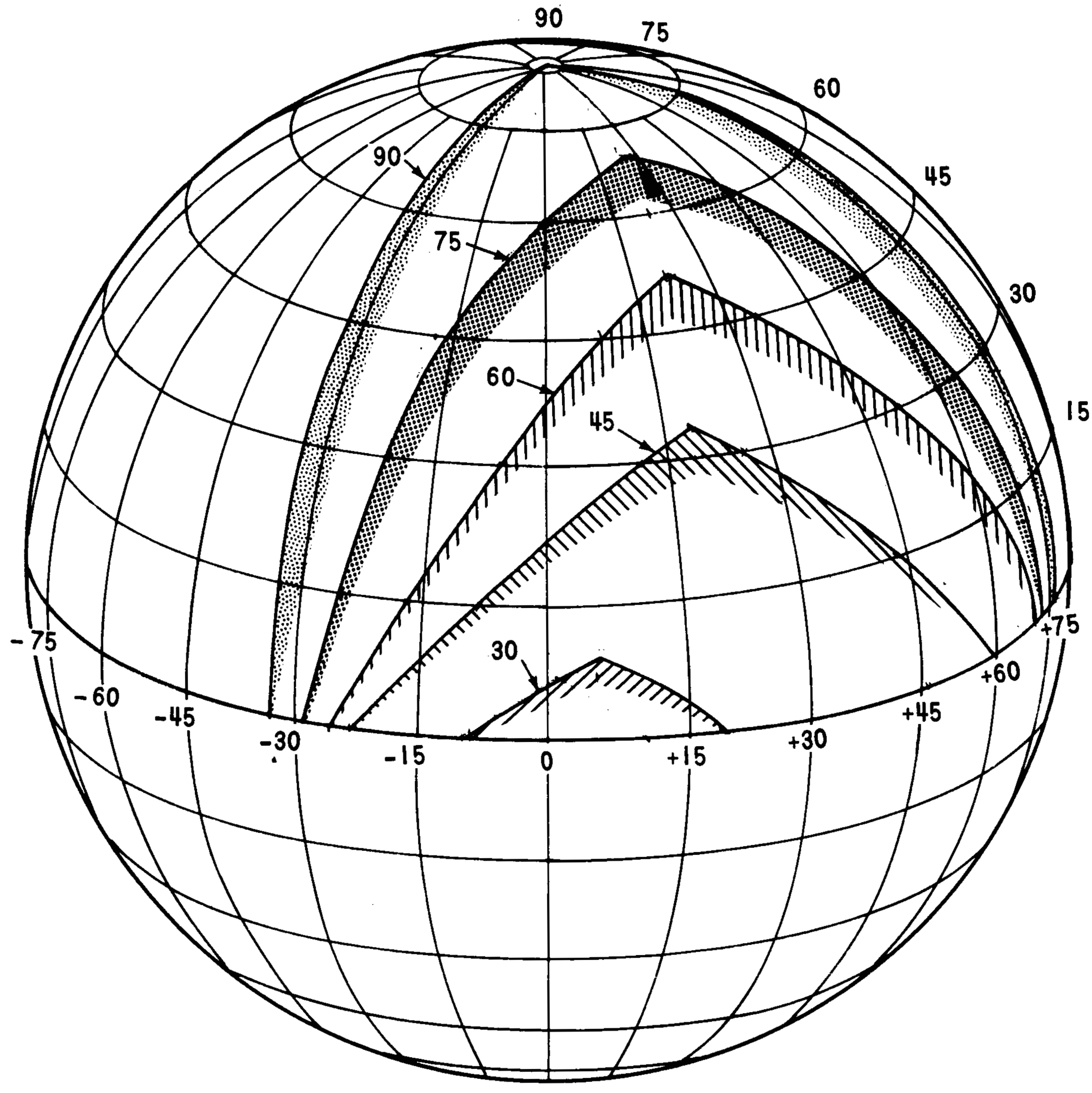


FIGURE 16 - RESTRICTIONS ON ACCESSIBILITY CSM & LPM MODIFIED

## APPENDIX

### Approximate Mission Design to the Lunar Surface

Point D on Figures 13B, 13C, and 15 has the coordinates 55°N and 60°E. Checking the accessbility on Figure 15, we find that it is accessible with a 60° orbit. It is also just accessible with a 75° orbit (both with configuration 1). Assuming that we would like to maximize coverage, we choose the 75° orbit. (If we wished to increase the payload we might have chosen the 60° orbit.) From Figure 13B we find that the 75° orbit overflying point D has an ascending node longitude at 84°E.

From Figure 9 we find that the TL flight time is 132 hours and that all the available $\Delta V$ has been used. Provided that no abort was called for, we find that the CSM at the end of the mission has approximately 4360 fps available for TEI (not including 100 fps for midcourse and thus can perform a TEI with approximately 80 hours flight time.

BELLCOMM, INC.

Subject: LPM Landing and 14 Day CSM Orbital Missions

From: I. Silberstein

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